Development of electrochemical biosensors for the measurement of physiological parameters in sweat for wearable applications

Valeria Belén Colmena Rubil

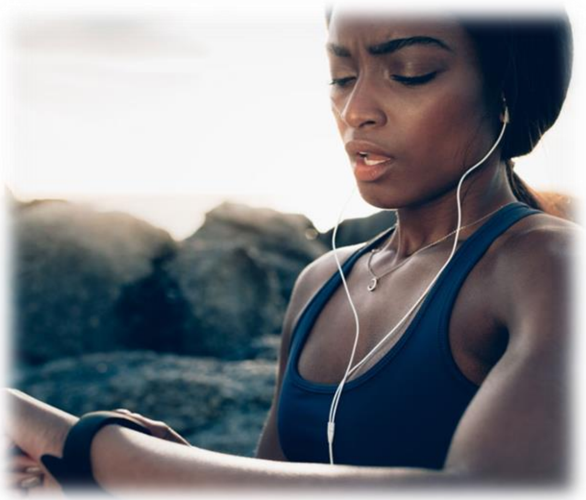
Universitat Autònoma de Barcelona

Advisors: Jaime Punter Villagrasa, Xavier Francesc Muñoz Berbel, Gonzalo Guirado López

1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

1. INTRODUCTION

Monitoring metabolites in the sweat of athletes is of great importance in assessing their metabolic state and optimizing their performance.



For continuous and remote monitoring of an athlete, **amperometric and potentiometric sensors** are important for measuring and monitoring various key biochemical variables.

- Lactate amperometric sensor
- Glucose amperometric sensor
- Sodium and potassium potentiometric sensor

Continuous monitoring of these variables allows for more precise adjustment of training strategies and hydration, which can have a significant impact on athletic performance and athlete's health.

1. INTRODUCTION

UAB
Universitat Autònoma de Barcelona

In order to obtain a more comprehensive perspective on the significance of all parameters:

Physical performance	Electrolyte Balance and Hydration	Detection of Health Issues	Training and recovery optimization

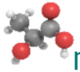
Glucose and Lactate → Glucose levels in sweat can indicate how the body is using its glycogen reserves and whether carbohydrate intake needs to be adjusted before, during, or after training. Lactate in sweat can help evaluate exercise intensity and determine if the athlete is working at their anaerobic threshold.

Sodium and Potassium → Measuring sodium and potassium in sweat can help determine individual electrolyte replacement needs and accurately adjust hydration strategies.

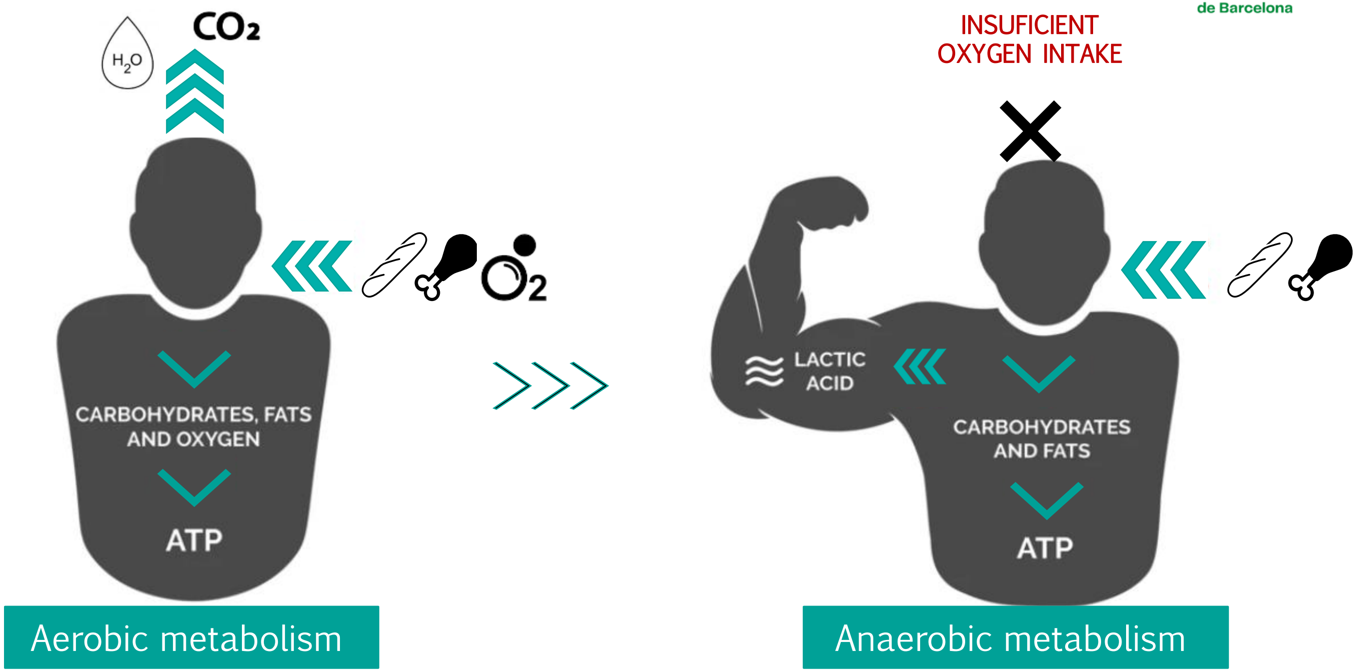
onalabs

UAB Universitat Autònoma de Barcelona

Why is it important to measure lactate through sweat?



L-lactate is a metabolite that is the indicator of the transition from aerobic to anaerobic.



- ✗ Lactate tests need blood sample taken from earlobe through a needle that causes great disadvantage in real-time monitoring.
- ✓ Measuring in sweat makes the process easier and coaches will have the capacity of checking in real time the fatigue of athletes.

onalabs

UAB Universitat Autònoma de Barcelona

1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

2. STATE OF THE ART

Lactate sensors developed to date:

Reference	Area WE (mm)	Funcionalization	Lineal range	Sensitivity	Sample volume	Detection limit
Yashina et al. Biosensor for lactate detection [1]	1.9	Sol–gel based Prussian Blue modified electrode	0.01-1 uM	0.18 (A/M·cm)	50uL	10 uM
Shimomura et al. Biosensor for lactate detection [2]	1.6	Nafion/cobalt phthalocyanine/poly-vinil alcohol	18.3 uM -1.5mM	-	100uL	-
Avramescu et al. Biosensor for lactate detection in food [3]	2	2 uL D-lactate dehydrogenase (2.7 mg/ml)	0.1-1 mM	10.8 (%)	25uL	0.05 mM
Payne et al. Biosensor for lactate detection in sweat [4]	-	Chitosan+ CNT (carbon nanotubes) + TTF + LOx	1-24 mM	4.8 (uA/mM)	-	-
Wei et al. Biosensor for the detection of lactate in food [5]	1.6	Chitosan+LOx	50 nM	0.23 (A/M·cm)	-	-

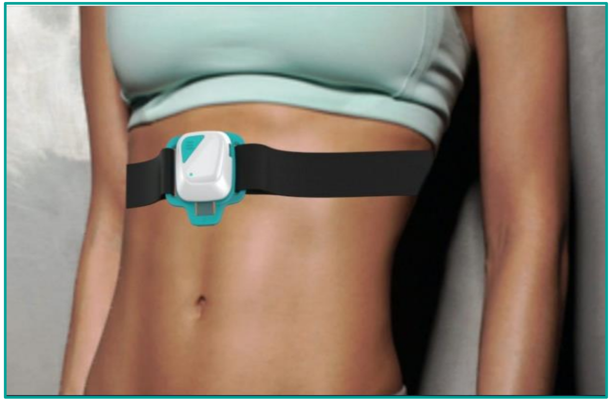
[1] doi: 10.1021/ac9027615
[2] doi: 10.1016/j.aca.2011.11.053
[3] doi:10.1016/S0003-2670(00)01386-6
[4] doi:10.1038/s41598-019-49689-7
[5] doi: 10.1021/ac020765k

2. STATE OF THE ART

The sensors is intended to be integrated within a monitoring device:

non-invasive, continuous, and remote operation through **sweat analysis.**

This device will satisfy the need of sports medical personnel for a more accurate training and recovery protocols of athletes.



Body-fluid collection → In vitro laboratory tests → In vivo stress test → In vivo device test

2. STATE OF THE ART

Some of the current devices that offer some of these features are:

Company	Product	Non-invasive	Continuous monitoring	Lactate measurement	Sweat rate / Dehydration	Developed for sport
Eccrine Systems, Inc. SWEATRONICS		✓	✗	✓	✗	✗
KENZEN		✓	✗	✗	✗	✗
PKvitality		✗	✓	✓	✗	✓
Laktate www.laktate.com		✗	✗	✓	✗	✓
EPICORE BIOSYSTEMS		✓	✗	✗	✓	✓

2. STATE OF THE ART

The current design allows the integration in the disposable of up to these sensors:

- **Heart** rate
- **Sweating Rate** sensor
- **Conductivity** sensor
- Amperometric sensor for **lactate**

In this first line of work, a sensor will be developed to measure lactate.

However, in subsequent steps, sensors will also be developed to measure glucose, sodium, and potassium.

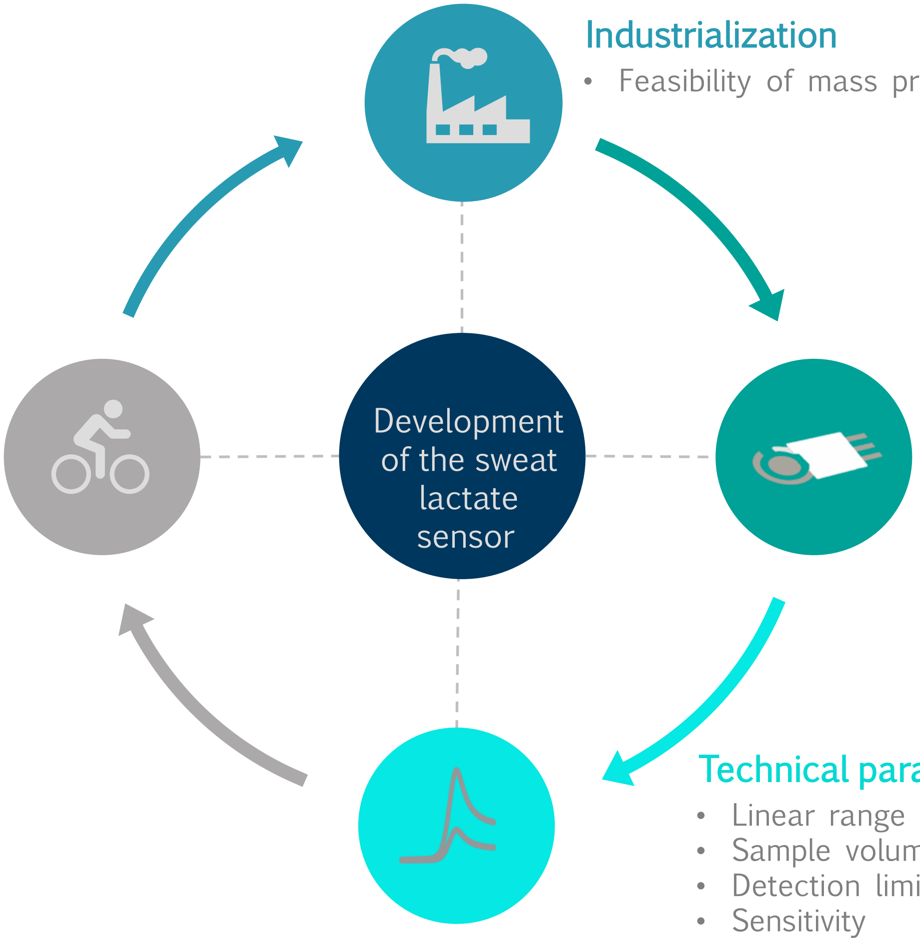
2. STATE OF THE ART

The parameters that **this device** offers us compared to the others:

Company	Product	Non-invasive	Continuous monitoring	Lactate measurement	Sweat rate / Dehydration	Developed for sport
|onalabs)		✓	✓		✓	✓
Eccrine Systems, Inc. SWEATRONICS		✓	✗	✓	✗	✗
KENZEN		✓	✗	✗	✗	✗
PKvitality		✗	✓	✓	✗	✓
Laktate www.laktate.com		✗	✗	✓	✗	✓
EPICORE BIOSYSTEMS		✓	✗	✗	✓	✓

1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

3. OBJECTIVES



Industrialization
- Feasibility of mass production

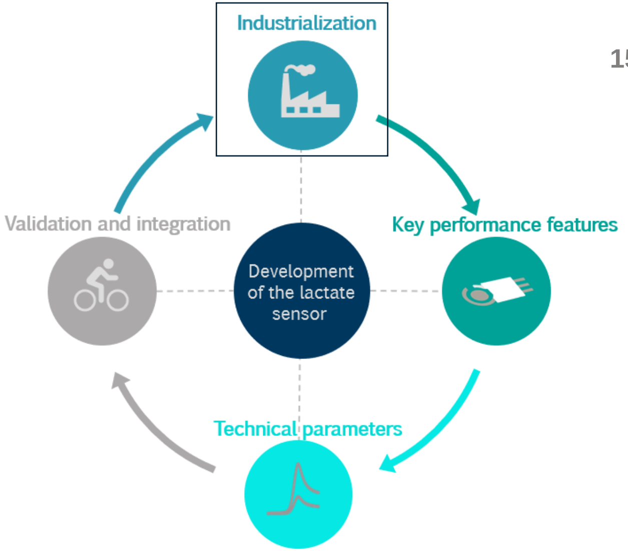
Key performance features
- Stability
- Durability

Technical parameters
- Linear range
- Sample volume
- Detection limit
- Sensitivity
- Selectivity

Validation and integration
- Efficient integration
- Validation in athletes

1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

4. METHODOLOGY



Feasibility of mass production

Screen printing method for sensors → a versatile technique for fabricating printed sensor elements

4. METHODOLOGY

Sensor membrane characterization techniques

IR Spectroscopy

Thermogravimetric analysis(TGA)

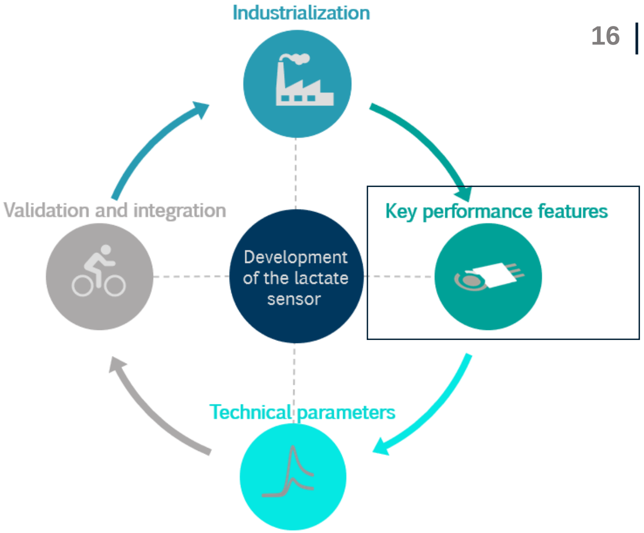
Scanning electron microscopy (SEM)

X-ray Diffraction (XRD)

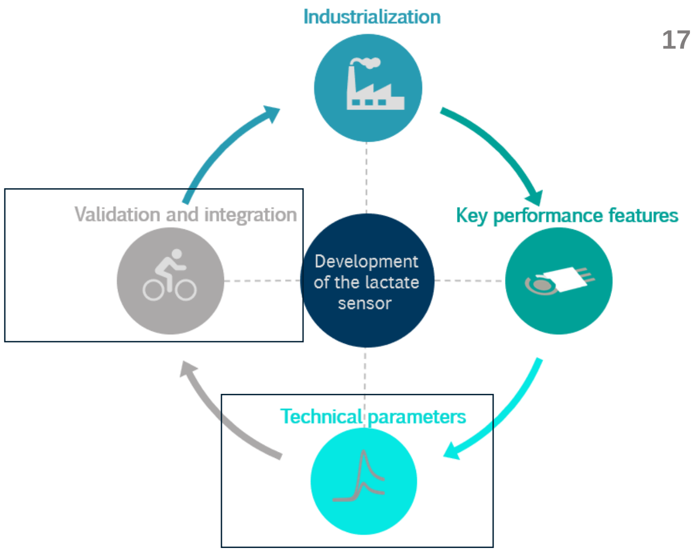
Permeability testing

Surface Roughness (AFM)

Confocal Laser scanning



4. METHODOLOGY



Electrochemical characterization techniques

Electrochemical techniques:

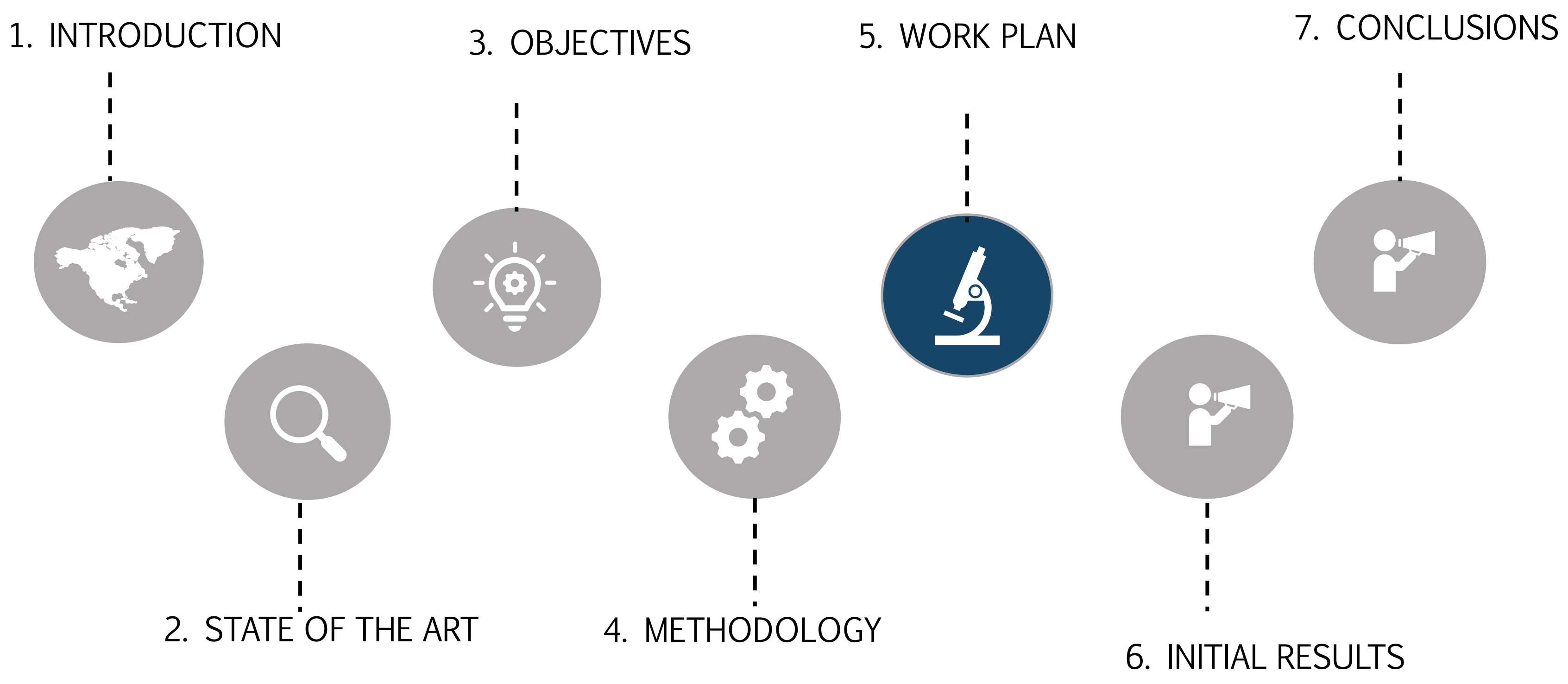
-Voltammetry

-Amperometry

-Potentiometry

- Electrochemical impedance spectroscopy

Integration into device


1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

5. WORK PLAN

WP	Year 1				Year 2				Year 3			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
1	X											
2		X	X	X	X	X						
3							X	X				
4									X	X		
5											X	
6												X

✓ **WP1:** Definition of requirements and user specifications

» **WP2:** Develop and fabricate an electrochemical biosensor

WP3: Validation and optimization in artificial sweat

WP4: Integrate the sensors in the sweat capture system

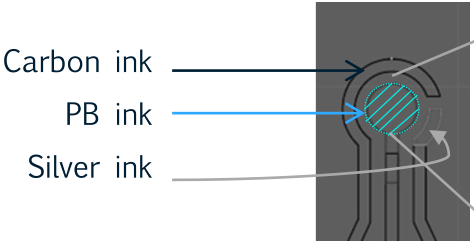
WP5: Validation: in-vitro and in-vivo laboratory testing

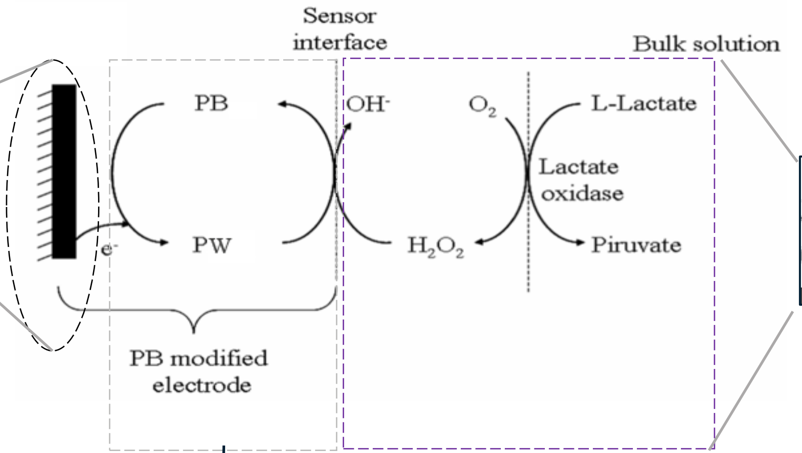
WP6: Thesis Writing and Defence

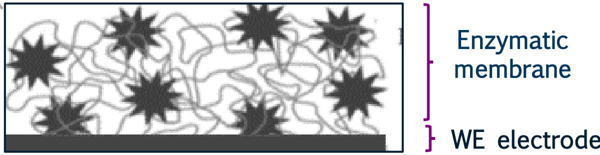
1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

6. INITIAL RESULTS

WP2: Develop and fabricate an electrochemical biosensor







✅ Industrial development

Biocompatible polymeric membrane

✅ Stability

✅ Durability

Deposition techniques for Prussian blue:

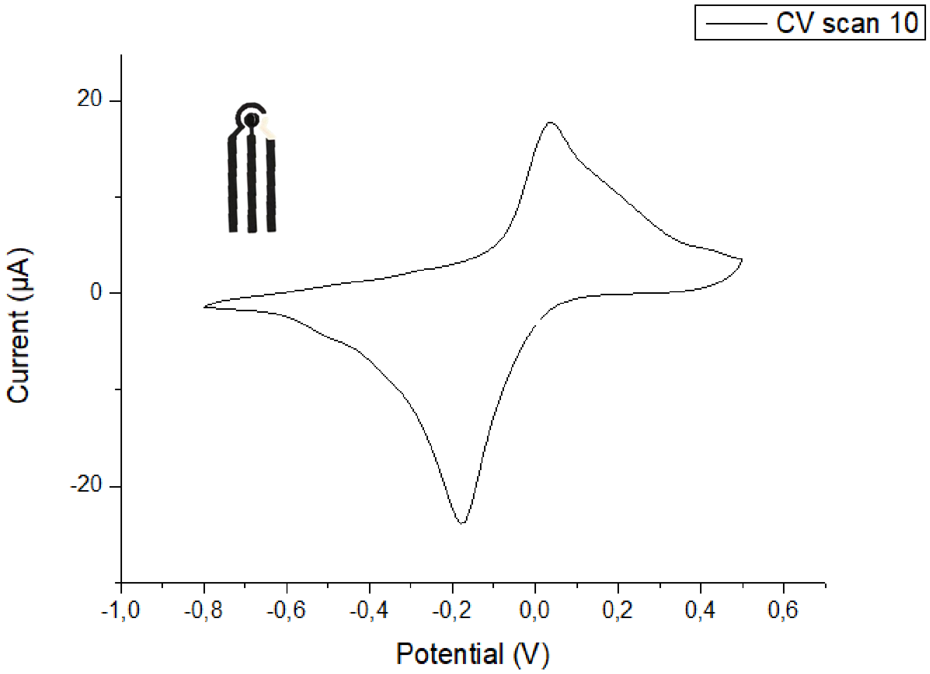
- ❑ Potentiostatic electrodeposition
- ❑ Chemical deposition
- ☑ **Screen-printed Prussian blue**

6. INITIAL RESULTS

|onalabs)

UAB Universitat Autònoma de Barcelona

WP2: Develop and fabricate an electrochemical biosensor



Sample volume

Selectivity

Cyclic scan voltammogram 10t of sensor using 3ul of artificial sweat. Oxidation peak around 0.17 V and reduction peak at -0.05 V.

Current range (μA)	-20 – 20
Oxidation peak (V)	~ 0.17
Reduction peak (V)	-0.05

6. INITIAL RESULTS

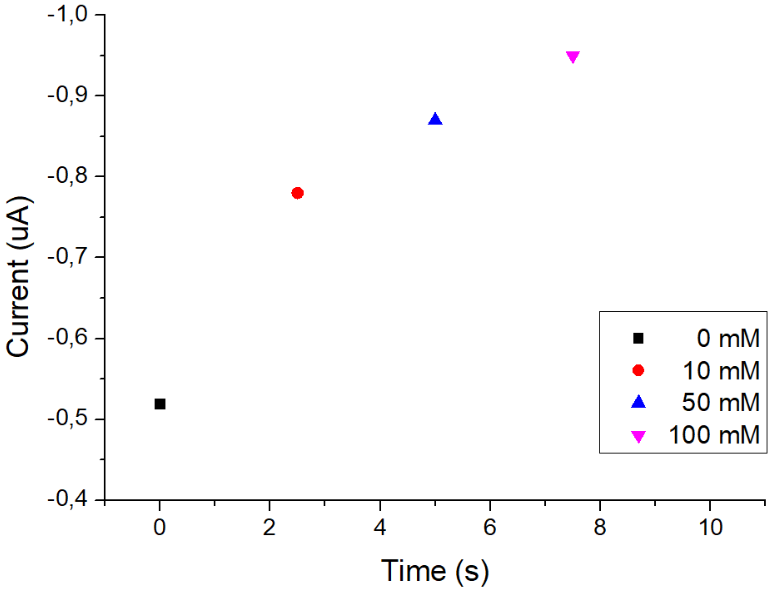
WP2: Develop and fabricate an electrochemical biosensor

- In all the measurements performed, **a drop of 3 ul of artificial sweat was deposited on the sensor.**
- Also, it is tested in increasing concentrations of lactate.

Apply one chronoamperometry at -0.3V for 30''

Time (min)	[Lactate] (mM)	Current value (µA)
0	0	-0,52
2,5	10	-0,78
5	50	-0,87
7,5	100	-0,95

Average of the current values from second 15 to 30 of the chronoamperometry



Linear range

Detection limit

1. INTRODUCTION
2. STATE OF THE ART
3. OBJECTIVES
4. METHODOLOGY
5. WORK PLAN
6. INITIAL RESULTS
7. CONCLUSIONS

7. CONCLUSIONS

The developed design and fabrication process produce a sensor with good performance.

- Industrial development (screen printing PB)
- Measurament range from 10-100mM
- Sample volume of 3 µl
- Detection limit of 10 mM
- Durability of 2 months
- Stable and selective

Further work will focus on optimizing and improving the reproducibility and sensitivity of the sensor to proceed with its integration into the device.

The next step will involve working on the glucose sensor, applying all the knowledge gained from this initial development of the lactate sensor

Development of electrochemical biosensors for the measurement of physiological parameters in sweat for wearable applications

Valeria Belén Colmena Rubil

Universitat Autònoma de Barcelona

Advisors: Jaime Punter Villagrasa, Xavier Francesc Muñoz Berbel, Gonzalo Guirado López